AEDC

Arnold Engineering Development Center
Arnold Air Force Base, Tenn. 37389

An Air Force Materiel Command Test Facility

America's Aerospace Advantage

Test Before Flight www.arnold.af.mil

Propulsion Wind Tunnel

Arnold Engineering Development Center, (AEDC) located in southern Middle Tennessee, is the nation's largest aerospace ground test facility complex. The complex includes 58 aerodynamic and propulsion wind tunnels, rocket and turbine engine test cells, space environmental chambers, arc heaters, ballistic ranges and other specialized test units. Twenty-seven of the test units have capabilities unmatched in the United States and 14 have capabilities unmatched in the world. Using its ground test facilities, AEDC supports propulsion, aerodynamic, reentry, trans-atmospheric and space-flight systems testing.

Photo no. 0106402

A model of the Boeing 767-400ER aircraft in the center's 16-foot transonic wind tunnel.

Terms to Know

Mach number—a ratio unit of speed, named after Austrian philosopher and physicist Ernst Mach (1838-1916), used when talking about aircraft or missiles; defined as a ratio of the speed of an aircraft to the speed of sound in the undisturbed medium (air) through which the body is traveling. Mach 1 is approximately equal to 717 miles/hour at sea level.

Transonic—speeds at or near that of sound.

Supersonic—speeds above Mach 1.

Stores—fuel tanks, bombs, external pods or missiles that are carried by an aircraft.

AEDC Wind Tunnels

AEDC's wind tunnels include the Propulsion Wind Tunnels (16T, 16S and 4T), the von Karman Gas Dynamics Facility (VKF) Supersonic and Hypersonic Wind Tunnels A/B/C and the remote Hypervelocity Tunnel 9 Wind Tunnel, located in White Oak, Maryland. Individual fact sheets are available for further information on Hypervelocity Tunnel 9 and VKF Supersonic and Hypersonic Wind Tunnels.

Propulsion Wind Tunnel Facility

The PWT facility is composed of the 16-foot transonic (16T), 16-foot supersonic (16S) and the aerodynamic 4-foot transonic (4T) wind tunnels.

Devoted to aerodynamic and propulsion integration testing of large-scale aircraft models, PWT is used to provide AEDC's customers with complete testing and analysis capability. In some cases, the propulsion systems and inlets are tested simultaneously to make sure they are aerodynamically designed to provide adequate airflow to the engines. Other tests involve store separation investigations—making

Photo no. 00-29306

The Lockheed Martin X-35 Joint Strike Fighter Demonstrator in the 16-foot transonic wind tunnel.

Photo no. 00-24005

The Boeing X-32A Joint Strike Fighter Demonstrator in the 16-foot transonic wind tunnel.

Photo no. 95012117

A Navy F/A-18E/F Super Hornet store separation test in the center's 16-foot transonic wind tunnel.

sure bombs, missiles or other externally-carried stores separate cleanly from the parent aircraft when released.

The facility boasts some of the most powerful electric motors ever built—tall as a two-story house and as heavy as a railroad locomotive. Four motors—two at 83,000 horsepower each and a smaller pair rated at 35,000 horsepower each—were built to drive five compressors that generate wind speeds (airflow) in excess of 2,000 miles per hour in PWT's transonic and supersonic tunnels. Both 83,000-hp motors stand 21-1/2 feet high and weigh 225 tons with 31 miles of copper wire used in the motor windings. All four motors mounted one after another are longer than two football fields. New 60,000-hp motors are scheduled to replace the 35,000-hp motors by 2004, permitting wind tunnel testing operations to continue in the event one of the motors is down for repairs.

Designated an International Historical Mechanical Engineering Landmark in 1989 by the American Society of Mechanical Engineers, PWT has seen and will continue to see necessary improvements to keep AEDC a world-class competitor with wind tunnels built in the last 15 years.

16T and 16S

The facility has two 16-foot-square, 40-foot long test sections, closed-circuit wind tunnels, one transonic (16T) and one supersonic (16S). The 16T facility is capable of being operated at Mach numbers from 0.06 to 1.60. The 16S facility is capable of operation from Mach numbers from 1.60 to 4.0. Both 16T and 16S are used for conventional aerodynamic tests and for combined aerodynamic/propulsion systems tests. Pressure of the airflow through the test sections can be varied to simulate altitude conditions from sea level to about 150,000 feet.

The large tunnel size also allows for full-scale missile installations to test engine performance and airframe aerodynamics. Rocket propulsion systems and problems associated with their external aerodynamics are also investigated. Because of their large size, the PWT 16-foot tunnels are adaptable to the testing of parachutes or other decelerators. Using specially built inanimate dummies, measurements have been made of the aerodynamic forces acting on the human body during emergency ejection from an aircraft traveling at speeds up to 900 mph.

Photo no. 0106402

A model of the Boeing 747X aircraft in AEDC's 16-foot transonic wind tunnel.

Both large tunnels have interchangeable test sections, allowing preparations for one test to be made while another is being run in the tunnel. To eliminate swirling and turbulence, which could affect test results, the airflow is guided smoothly around the right-angle turns of the closed-circuit tunnels by giant turning vanes that resemble huge, vertical venetian blinds. A flexible nozzle regulates the velocity of the airflow as it enters the test section.

Some of the features of tunnels 16T and 16S include a moveable support system called a strut. The strut is attached to the floor of the wind tunnel's test section. The tunnels are also equipped with a special movable support system, called a sting, for mounting additional models. To simulate change in flight attitudes or maneuvers, the support is yawed (moved side to side), rolled or pitched up or down.

The 16-foot tunnels are often used to examine the relationship between engine air inlets and the corresponding performance of and compatibility with the engine itself. This is done to determine the most efficient air-induction system design or to study how varying the geometrical shape of an inlet or propulsion nozzle can affect the aerodynamics of the flight vehicle. Both tunnels also have a scavenging system that removes combustion products when testing rocket motors or gas turbine (jet) engines.

4T

The aerodynamic wind tunnel 4T is PWT's versatile, mid-size test unit that has a 4-foot by 4-foot by 12.5-foot long test section. The transonic designation indicates its primary utility is for testing from subsonic to low end supersonic airspeeds. Its capability is roughly equivalent to an airspeed range from 160 to 1600 miles per hour.

Photo no. 0030613

An F-111 store separation test in the 4-foot transonic wind tunnel.

Store Separation Testing

At transonic speeds, and at certain altitudes or maneuver conditions, the aerodynamic forces on an aircraft's stores—bombs, missiles or drop tanks carried externally—separating from an aircraft, may cause the store to veer upward when released and collide with the aircraft.

In years past, bombs were carried and dropped out of bomb bays. But as high-thrust engines became available, the weapons could be shifted outside and carried in considerable numbers on pylons attached to the lower surface of the wings, or carried in numbers in an internal weapons bay. Problems became evident when the aircraft speed became progressively faster.

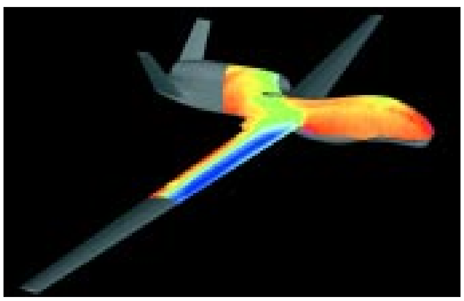

Photo no. 97-03259

A computational fluid dynamic (CFD) generated image of the Global Hawk unmanned air vehicle.

The problem of clean store separation—investigations of aerodynamic forces that can alter the planned trajectory of air-launched bombs or missiles—is explored in 16T, 16S and 4T.

The aircraft model is mounted upside down in the tunnel on a support system called a strut. The strut is attached to the floor in the test section of the wind tunnel. The store model is mounted on a special moveable support system called a sting attached within the test section and positioned very close to the aircraft as it would be in flight. When the desired simulated flight conditions are established in the tunnel, the store model is "launched" from the parent aircraft model by activating a computer that controls movement of the sting-supported store as it traces the trajectory.

Information obtained in these tests is used to design new stores or to modify existing ones, or modify carriage and release mechanisms to make sure they separate cleanly, do not damage the parent aircraft, and stay on the intended flight path in the proper attitude.

Captive Trajectory Support Testing

The Captive Trajectory Support (CTS) systems for the AEDC wind tunnels allows computer-controlled, six-degrees-of-freedom positioning of a missile, bomb, or any other store in close proximity to the aircraft (parent) model. Operational CTS systems exist in tunnels 4T and 16T, with CTS potential available in tunnel 16S. Applications in the PWT transonic and supersonic test units consist of store separation and flow-field mapping.

Photo no. 99082505

A model of the F-16 Fight Falcon aircraft in the 16-foot transonic wind tunnel with pressure sensitive paint applied to its surface.

Pressure-Sensitive Paint Capability

In 1999, a Multi-View Pressure Sensitive Paint Data Acquisition System was installed in 16T. PSP can determine the surface pressure at several hundred thousand locations on wind tunnel models while conventional instrumentation is limited to several hundred pressure openings. Also, pressure orifices cannot be installed in some areas of the model, such as thin surfaces, limiting the measurement of the surface pressure. PSP measurements are only limited if there are areas of the model that cannot be seen by one of the cameras.

AEDC became involved with the ever-evolving technology of PSP in 1993. The technique uses a special paint and illumination source combined with an extremely sensitive camera to obtain surface pressure data. PSP paint is applied to the model in two layers—a white undercoat and the PSP layer. The white undercoat provides a uniform reflective surface for the PSP layer. The illumination source excites the PSP layer, which fluoresces with intensity inversely proportional to the surface pressure on the model.

A pressure sensitive paint computational generated image of the F-16 Fighting Falcon.

Computational Support to Test and Evaluation

AEDC provides a wide range of computational support to the test and evaluation process that affects how the Army,

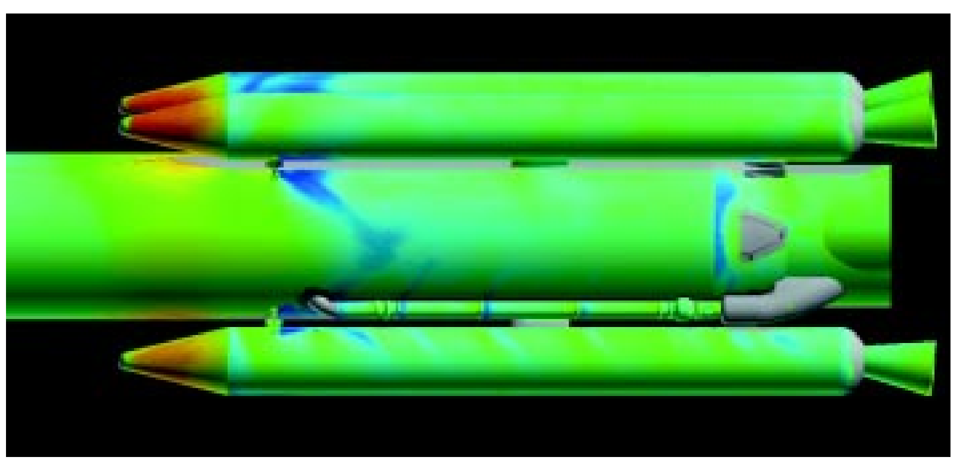

Photo no. 09910035

A computational image generated image of an Evolved Expendable Launch Vehicle (EELV) coated with pressure sensitive paint.

Photo no. 0040009

The B-1B Lancer bomber and the Joint Air to Surface Standoff Munition undergoing store separation testing in the 16-foot transonic wind tunnel.

Navy and Air Force develop new weapons systems. Calculations are used for several reasons, but one of the main reasons is to try and predict in advance what will happen during the test. Knowing this information allows test engineers to be better prepared for the test and to know beforehand of any problem areas. Another reason computations are used to support testing is to reduce the amount of testing that was once required. For example, certain types of testing requires the tunnel to be run at many different settings (Mach number, temperatures, pressures, etc.), but the number of settings might be reduced if this information can instead be generated using computational simulation.

The center is continually updating and improving the way it conducts computational studies because of several factors, such as improvements in computational techniques and improvements in computers (for example, computers are getting faster and less expensive every year). AEDC also works with companies, universities and other government agencies (e.g., NASA) in partnerships and alliances because much more can be accomplished working as a team than can be working alone.

The combination of using computations together with the wind tunnel results in a process known as Integrated Test and Evaluation (IT&E). Similar to people working as a team, much more can be accomplished using computations and the wind tunnel as a "team" than can be accomplished by either working by itself. Using the IT&E approach allows AEDC customers to test more efficiently and with less risk. Performing pre-test predictions of the behavior of the test article in the tunnel allows the test plan to be optimized and allows more usable information to be processed thus increasing the test product value by saving the customer time and money as well as reducing risk to the program.

Photo no. 99-0517-209

The data visualization technology currently employed for data display in the center's 16-foot wind tunnels.

21st Century Testing Technology

An Air Force-funded program, scheduled for completion by the end of 2004, provides AEDC with 21st century testing technology. Known as the Propulsion Wind Tunnel Sustainment Program, the program will fully automate the PWT test facility in four phases. Improvements from the program include installation of all new data acquisition and control systems in PWT's 16-foot transonic and supersonic wind tunnels, model installation building and operation plants.

Photo no. 99-071804

The F-22 Raptor, the Air Force's new air dominance fighter during store separation testing in AEDC's 16-foot transonic wind tunnel.

Propulsion Wind Tunnels Background

Planning for the Propulsion Wind Tunnels (PWT) began in January 1950, when the Air Force Research and Development Board on Facilities met with representatives of aircraft propulsion companies and agreed that industry needed a supersonic propulsion wind tunnel with a 15-foot-diameter test section.

By December 1951, the commanding general at AEDC had approved a proposal for design, construction and operation of a scale model of the PWT transonic circuit. The initial test facility was a one-foot cross-section prototype transonic tunnel, and the first test was performed June 1953 on a 0.03-scale model of the Bomarc missile for the Boeing Company.

In 1956, the transonic circuit, with its 16-foot test section, underwent its first powered operation preliminary to calibration.

The entire PWT complex was accepted by the Air Force in January 1961. The approximate cost of the 39 contracts to construct the facility was $78.7 million.

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Release # 2002-082